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# A Circuity Cost Model for Rehabilitation/Closure of Rural Bridges: A Wayne County, Ohio, Application

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# A Circuity Cost Model for Rehabilitation / Closure of Rural Bridges: A Wayne County, Ohio, Application

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## SUMMARY

This research focuses on the development of a circuity cost model that can be used to estimate the cost to road users of re-routing traffic when rural roads or bridges are posted or closed to traffic. The model is used to rank a sample of 15 bridges in Wayne County, Ohio, for repairs or replacement based on the net re-routed costs to users. These results are then compared to a ranking of the sample by staff of the Wayne County Engineer's Office. The model incorporates all users of the bridge by weight class as well as the alternative rehabilitation scenarios available in the county. It also considers bridge closure, weight posting, and rehabilitation, while making provisions for weight violations and changes in annual maintenance costs. A sensitivity analysis is performed on the discount rate to help generalize the results.

## BACKGROUND AND PROBLEM

About 70% of the rural roads and bridges in the United States were built before 1935 to accommodate trucks up to 8 tons gross weight.[2] Baumel (3) reports that most of these roads and bridges have now deteriorated and are unable to support the fleet of heavy trucks on the roads today.

Highway statistics from the U. S. Dept. of Transportation (24) reveal that by December 1979 there were about 170,488 bridges that were not on the federal aid highway system. About 43,317 or 25% of these bridges are structurally deficient.[3] Another 40,614 or 24% are functionally obsolete.[4] The number of deficient[5] bridges adds up to 82,931 or 49% of the total non-federal aid bridges.

The causes of road and bridge deterioration are aging, inadequate maintenance due to declining revenue, and increasing volume of heavy trucks on the roads. Natural phenomena such as rainfall, freezing, thawing, and severe winters also contribute to the problem.

Roads and bridges are maintained with revenue from the gasoline tax, vehicle registration fees, fines and parking, property taxes, and general revenues. The gas tax remains the most significant single source of revenue in Ohio. Since 1973, rapid increases in the price of petroleum products have caused a decrease in gasoline consumption, with a corresponding decrease in gas tax revenue. At the same time, the cost of road construction materials such as asphalt and bitumen have gone up considerably. The net effect is a widening gap between rehabilitation cost and revenue.

The increase in number and weight of heavy trucks is the major cause of road/bridge deterioration. It has been determined that concentrating large amounts of weight on a single axle multiplies the impact of the weight exponentially. A CED report states that an 80,000 lb 5-axle tractor trailer weighs as much as 20 automobiles, but the impact of the former on the road or bridge is the same as at least 9,600 automobiles. Weight enforcement efforts are difficult and expensive. In additon, the penalty-fine structures are too low to deter most weight violations.

It is argued that overweight trucking cuts down on the number of trips and consequently reduces truck fuel consumption and operating expenses. Some evidence from Stanford Research Institute, F.H.A., and other sources tends to support this fuel saving argument. However, overweight trucks also cause surface deterioration which increases fuel consumption for all vehicles—not just trucks. Given the constraints on road and bridge budgets, liberal weight laws could lead to extensive deterioration of rural roads and bridges.

Most county authorities rely on closing or posting bridges that pose severe safety hazards as a temporary solution to the problem. Officials also must make decisions regarding repair, replacement, or maintenance of some bridges ahead of others. Closing or posting bridges could be costly because of the important role road transportation plays in mobility of people and goods. Motorists might incur extra costs via re-routing. Some motorists also violate the posted limit and cause more severe damage to the

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[2]Rural roads and bridges in this research refer to those for which the county or township is responsible for repair, maintenance, widening, reconstruction, and resurfacing.

[3]A structurally deficient bridge is one that has been restricted to light vehicles or closed.

[4]A functionally obsolete bridge is one with deck geometry, load capacity, clearance, or approach roadway alignment which can no longer service the system of which it is an integral part.

[5]A deficient bridge is one that is functionally obsolete or structurally deficient. This term is used synonymously with a deteriorated bridge in this research.

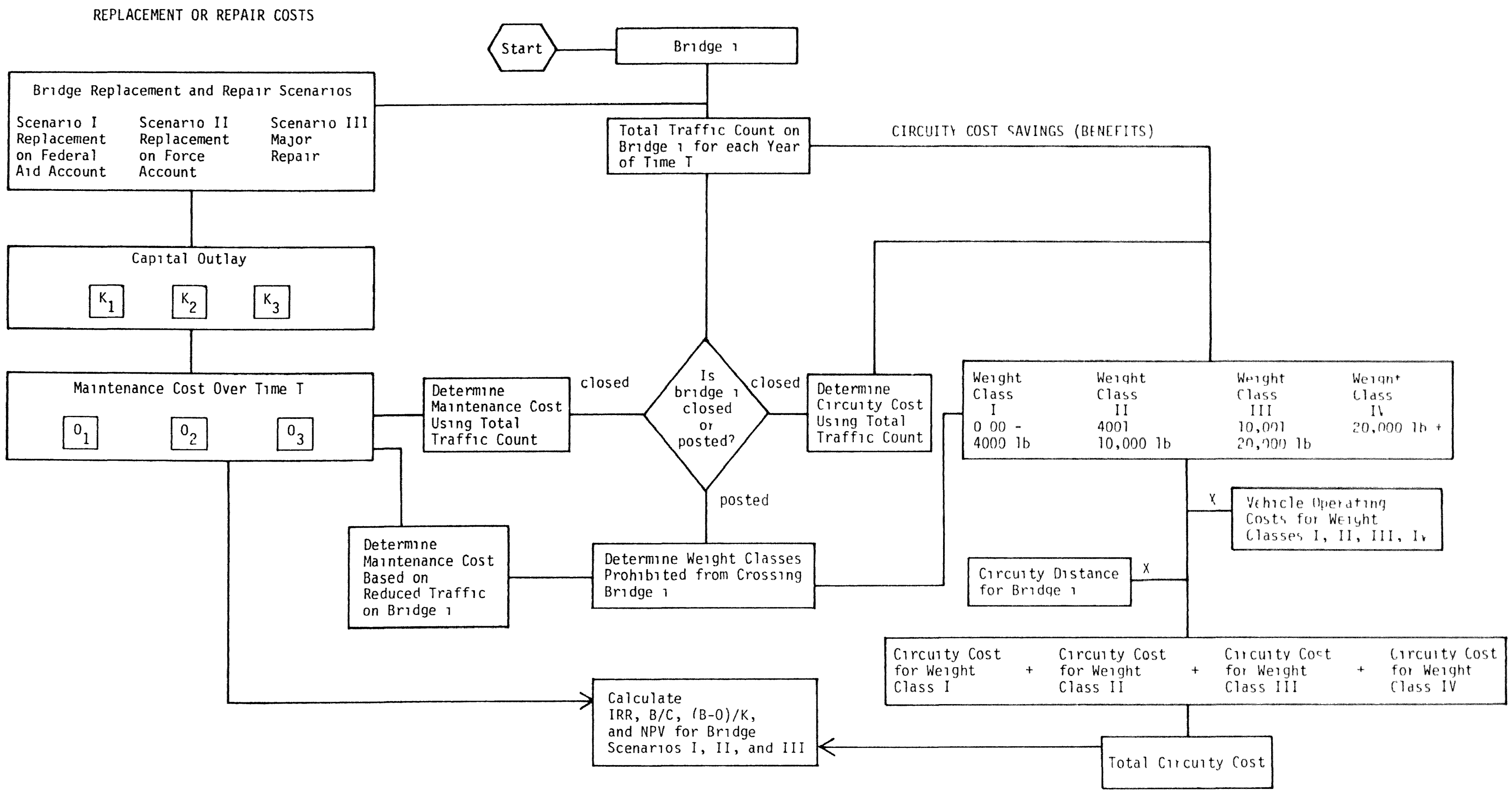


**FIG. 1.—Flow chart for rural bridge rehabilitation/closure circuity cost models.**

bridge or road. Thus, there is a need to assess the impact of closure or posting of roads or bridges on users, and to develop a procedure for prioritizing bridges for repair, replacement, or closure in order to ensure efficient allocation of scarce resources.

### Wayne County Bridge Problem

Like other counties in Ohio, Wayne County is responsible for the maintenance, repair, widening, resurfacing, and reconstruction of pavements and bridges in the county highway system (26). It also maintains some bridges within the municipalities and the state highway system. In all, the county is responsible for 537 bridges which are estimated to be 3.22 miles (in terms of bridge deck). Only 231 or 43% of the 537 bridges are structurally and functionally adequate. A total of 282 bridges or 53% are too narrow to support wide implements and large delivery trucks, and 93 bridges, or 17%, are load limited. Several bridges are both too narrow and load limited.

The ages of 97 bridges are not known. The average age of the remaining bridges is 48 years. The normal useful life of a bridge is estimated to be 50 years. Based on this 50 year life span, the average age of all the county bridges will exceed their useful lives within 2 years. This problem is accentuated by overweight trucking in the county related to coal and gravel mining and oil drilling rigs.

The county also faces severe budget problems. Expenditures on bridges and culverts averaged $280,925 per year from 1976 to 1980. However, the estimated cost of replacing just the 93 load limited bridges over the next 10 years is $705,000 per year. This implies that the county will be unable to meet all of its commitments and needs to prioritize bridges for repair, replacement, or closure in order to ensure efficient allocation of its resources.

## OBJECTIVES OF RESEARCH

The main objectives of the research are: 1) to develop a conceptual model for measuring the costs and benefits of rehabilitation, closure, or posting of a sample of rural bridges in Wayne County, Ohio; 2) to estimate and compare the costs and benefits of rehabilitation, closure, or posting of a sample of the rural bridges; 3) to prioritize bridges for repair, replacement, or maintenance based on the results in objectives 1 and 2 and compare to current judgemental priorities; and 4) to develop preliminary policy recommendations and a future research agenda based on the results of objectives 1, 2, and 3.

## GENERAL METHODOLOGY

Based on the research objectives and review of the literature, a cost-benefit (circuity cost) model based in part on conceptual work by Ridley (20), Johnson (13), Neuberger (15), and others is used for this analysis. This model estimates the cost of rerouting traffic when a sample of rural bridges is closed or posted and compares these costs with those of alternative scenarios for replacement, repair, and maintenance of each bridge.

In this model, benefits to road/bridge users are represented by total circuity cost. Total circuity cost is the private expense to all road/bridge users when that bridge is closed or posted. As a benefit measure, however, total circuity cost represents the expected cost savings to motorists when the bridge is re-opened to traffic or rehabilitated for heavier traffic.

A flow diagram of the circuity cost model is shown in Figure 1. To obtain the total circuity cost per bridge, a traffic count for each bridge is estimated by vehicle class based on gross vehicle weights. The total number of vehicles in each weight class is multiplied by their respective average per mile cost of motor vehicle operation and the circuity distance[6] to obtain the circuity cost for that particular weight class. Circuity costs for all weight classes are summed over time and discounted to obtain the net present value (NPV) of total circuity costs or potential benefits for that bridge.

The cost side of the model is represented by replacement, repair, and annual maintenance costs of each bridge. Three scenarios of bridge rehabilitation based on the initial capital outlay are identified: Scenario I, bridge replacement on a federal aid program; Scenario II, replacement on a force account; and Scenario III, major repairs.

Bridges replaced with federal aid in Scenario I require higher specifications in design and construction which result in large capital outlays and longer life expectancies. The force account replacement in Scenario II is where the county engineer acts as a contractor using county resources to design and construct the bridge. Capital outlays and life expectancies are comparatively lower than federal aid bridges in Scenario I. Major repairs in Scenario III involve reinforcing the existing bridge structure and therefore require small capital outlays. In this analysis, bridges which are repaired have life spans that range from 10 to 20 years depending on age of bridge and nature of repair, while bridges replaced on the federal aid and force account are assumed to last 50 and 45 years, respectively.

A benefit cost analysis using the circuity costs or potential benefits and the replacement, repair, and maintenance costs is carried out for each of the three scenarios. When the bridge is closed, all motorists

[6]Circuity distance is the extra distance traveled by motorists when a bridge is closed or posted.

re-route and consequently total circuity costs represent the benefits side of the model. However, when the bridge is posted the heavier fraction of total traffic re-routes. The classification of users into weight classes allows circuity cost to be estimated for only the re-routed traffic.

None of the potential secondary costs and benefits discussed by Dodgson (8) or others that are associated with closing or posting of bridges are accounted for by the model. These include such things as changes in commodity prices and air pollution levels, expenses on posted signs and law enforcement, and the income potential from the abandoned road beds.

## CIRCUITY COST MODEL(S)

Three alternative versions or decision criteria of the basic cost benefit model: net present value (NPV), modified benefit cost ratio [(B-O)/K], and internal rate of return (IRR) are developed for comparison purposes. A single computer run or estimation of each criterion generates a discounted present value of future benefits and costs for a specific repair or replacement scenario and a closure or posting assumption for a single sample bridge.

The modified benefit cost ratio [(B-O)/K] forms the basis for prioritizing bridges for repair or replacement. The conventional benefit cost ratio (B/C) is not used for the analysis because road and bridge repair and replacement are not usually financed from general revenues but rather from user charges such as gasoline tax, vehicle registration fees, and the axle mile tax. Since these user fees cover annual repair and maintenance costs (and some capital outlays), Howe argues that the (B-O)/K is more appropriate than the B/C ratio in evaluating these investments; *i.e.,* operating costs are not a capital constraint in the way that initial capital outlay may be (12). However, the (B-O)/K criterion does give a higher relative ranking to projects or bridges with low capital outlay and high operating costs.

The NPV is used to indicate how much in current dollars is lost by users when bridges are posted or closed, or conversely how much cost savings users should expect after rehabilitation of the bridges. The IRR compares the yield of the resources committed to the investment with their potential in other uses. Dasgupta and Pearce (7) discuss these and other criteria in more detail.

The models are:

$$(1)\quad NPV_{jkl} = \sum_{t=1}^{T}\sum_{u=1}^{U}\frac{\left[VOC_{ut}CD_{ut}N_{u}\right]}{(1+i)^{T}} - \left[\sum_{t=1}^{T}\sum_{u=1}^{U}\frac{O_{ut}}{(1+i)^{T}} + K\right]$$

$$(2)\quad \frac{B-O}{K} = \sum_{t=1}^{T}\sum_{u=1}^{U}\frac{\left[VOC_{ut}CD_{ut}N_{u} \;\; -O_{ut}\right]}{(1+i)^{T}} \div K$$

IRR = the i solved through an iterative procedure that makes:

$$(3)\quad \sum_{t=1}^{T}\sum_{u=1}^{U}\frac{\left[VOC_{ut}CD_{ut}N_{u} \;\; -O_{ut}\right]}{(1+i)^{T}} = K$$

where:

- j = a specific sample bridge
- k = type of major repair or replacement scenario
- 1 = closure or posted weight limit
- U = specific user or weight class
- T = life span of bridge or time period over which costs and benefits are measured
- i = discount rate
- IRR = internal rate of return
- VOC = vehicle operation cost to user U of bridge j ($/mile)
- CD = circuity distance or change in distance traveled by user U due to closure or posting of bridge j
- O = annual maintenance cost of bridge j for major repairs or replacement scenario k
- K = initial capital outlay of bridge j for major repair or replacement scenario k
- $N_u$ = the number of vehicles in weight class U that use bridge j

The term $VOC_{ut}$ represents total cost of motor vehicle operation to user U of bridge j over time period t in dollars/mile. Vehicle operating cost varies depending on road condition, type and age of vehicles, as well as behavioral differences among drivers. These variations are not accounted for in the model. Instead, the average vehicle operating cost for each weight class is used. Vehicle operating cost includes owning cost, cost of fuel, oil, tires, preventive maintenance, equipment depreciation, and repairs. Another component of vehicle operating cost is the time value of vehicle operators. Time value of operators is measured in terms of salaries or wages, insurance, and workmen's compensation for vehicle operators.

The term $VOC_{ut}$ $CD_{ut}$ is the product of the total vehicle operation cost/mile to user U of bridge j and the change in distance traveled due to posting or closure over time period t. Consequently, it is a measure of circuity cost in dollars to the user U. This cost generated over time period t is further multiplied by the number of users in each weight class ($N_u$) to obtain the circuity cost to that particular weight class. Circuity cost for all weight classes is summed to obtain the total circuity cost to all users. Future circuity costs are discounted to present value using the term $(1 + i)^T$.

The term K represents the initial capital outlay of bridge j for major repair or replacement scenario K. This cost is added to the discounted annual maintenance cost to obtain the total present value of repair, replacement, and maintenance costs.

The value of discounted benefits minus discounted costs is a measure of net present value (NPV), net benefits, or net circuity costs. The ratio of the present value of net benefits to the capital outlay costs is the benefit cost ratio (B-O)/K. The internal rate of return is that rate of discount that equates the NPV to zero. Therefore, IRR is estimated by setting the NPV to zero and solving equation (3) for i.

## SAMPLING AND DATA COLLECTION

Wayne County, Ohio, was used as the case county because of evidence of a serious problem of rural bridge deterioration and data availability. In addition, the county ranks eighth out of the 88 counties in Ohio in terms of bridge responsibility or number of bridges to maintain, and has a wide diversity of road users ranging from heavy coal trucks to light passenger vehicles.

The data requirements of the model are: annual traffic counts by weight class; circuity distance measurements; motor vehicle operating costs; and bridge repair, replacement, and maintenance costs. Traffic counts and bridge rehabilitation cost estimates were obtained from the County Engineering Department. Vehicle operating cost data were obtained from trucking companies, school districts, leasing and renting firms (such as Hertz Corporation), as well as USDA and other published cost studies.

Traffic was counted at intersections of township and county roads in the spring and summer of 1979, utilizing workers in the federal government jobs program (CETA). Differentiation between cars and trucks was made, but only limited differentiation between types and weights of trucks was made by CETA enumerators. These sample traffic counts were then weighted to obtain the average daily counts.[7]

Three bridge groups were identified based on the availability of traffic counts and the extent of structural deficiencies. The first group of 15 bridges had traffic counts and were posted because they posed safety risks to motorists. The second group of 154 bridges had no traffic counts, and the third group of 194 bridges had traffic counts for 1979.

A statistical analysis of bridge age and condition[8] using t and f-tests was used to test for differences in age and condition of these groups (Appendix I). The results revealed significant differences in age and condition, with mean ages of 68.42, 52.75, and 47.42 years for the first, second, and third groups, respectively. This analysis further revealed a bias of local officials in selecting relatively newer bridges and roads (or higher traffic locations) for the traffic count. However, 5 of the 15 high risk bridges and 10 of the 194 bridges with traffic counts were randomly selected for the analysis due to the limited resources for the study. This procedure was followed with the recognition that the sample is not fully representative of all the bridges in Wayne County. Accordingly, caution must be exercised in generating conclusions from the study results.

Of the 15 sample bridges, 8 do not qualify for federal aid replacement. Two bridges are classified as beyond repair by the county engineers. Thus, the total sample sizes in each scenario are: 7 bridges which qualify for federal aid replacement in Scenario I, 15 bridges which qualify for force account replacement in Scenario II, and 13 bridges which qualify for major repair in Scenario III.

Data on types and frequency of vehicles from the CETA traffic count were not adequate. This information had to be gathered from personal interviews of haulers and residents living close to the bridges. For school buses and grain, gravel, coal, and milk trucks that have consistent and regular routes, the information was obtained from the respective haulers or operators. This is the most costly phase of data collection and the most limiting factor to extensive model replication in other settings.

Road/bridge users were classified into four groups based on their gross vehicle weights. These classes range from: 0 to 4000 lb, 4000 to 10,000 lb, 10,001 to 20,000 lb, and vehicles more than 20,000 lb. The classification is related to the normal weight posting practices on the county bridges. In Wayne County, bridges are not normally posted below 2 tons or 4000 lb. This implies that the first weight class is not affected by weight posting. The last weight class is affected by the highest level of posting (30,000 lb limit) observed during the data collection period.

Circuity distances for the sample bridges were determined from a detailed county road and bridge map. The measurement was the extra distances in

[7]These are standard weights used by the County Engineering Department.

[8]Bridge condition is defined on a state rating system ranging from 9 to 0. A bridge rated 9 means it is new and needs no repair; a 0 means the bridge needs immediate replacement.

miles that motorists travel using the shortest alternative routes to their destinations when the bridges are posted or closed (Appendix II). These distances were checked by interviewing residents and users of the bridges.[9] Vehicle operating costs (Appendix III) are multiplied by circuity distances to get rerouting costs (Appendices IV and V).

Estimates of bridge maintenance costs and capital outlays for all three scenarios were provided by the county engineers (Appendix VI). The life expectancies of bridges in Scenarios I and II are estimated to be 50 and 45 years, respectively. For Scenario III, bridges' life spans range from 10 to 20 years after the repairs. To make a comparison of NPV among scenarios more meaningful, the life spans of bridges in all scenarios had to be standardized at 50 years. The adopted procedure was to replace or repair the bridges in Scenarios II and III after the expiration of their useful lives based on the initial cost estimates and a 10% annual inflation rate.[10]

All bridges in Scenario II were replaced after the initial 45 years of useful life, with replacement cost amortized over the next 45 years. For Scenario III, where life expectancies vary from 10 to 20 years, it was found that not all bridges could withstand more than one round of repairs without replacement. The decision to repair or replace the bridge was based on a state rating system for bridges (see footnote 8). All bridges rated 4 or less were replaced on force account after the first major repairs. Bridges rated more than 4 were assumed to withstand two successive repairs before being replaced on a force account. Annual maintenance cost is a function of the damage to the road/bridge. Since pavement damage increases exponentially with vehicle weight, the relationship between maintenance cost and vehicle weight is expected to be exponential. The exact value of this relationship has not been determined. As a conservative estimate, the axle mile tax was used as a proxy.

The axle mile tax is a road user tax based on the number of axles and mileage traveled by commercial vehicles. The rate structure ranges from 0.5 cent per mile to 2.5 cents per mile. Each vehicle weight class is identified in the appropriate tax bracket. The tax brackets serve as weights intended to reflect the extent of damage or maintenance cost by weight class. If the annual routine maintenance expenses represent the mean of a randomly distributed cost to all weight classes, then the maintenance cost per bridge reflecting all weight classes could be estimated by the function

$$O = \Sigma\, f_i\, W_i$$

where:

O is the total annual maintenance cost

$f_i$ is the damage weights based on the tax structure

W is the annual routine maintenance cost per bridge.

[9] The major weakness with this procedure is when the shortest route is also weight posted. Such a situation could lead to underestimation of circuity distances and hence circuity cost, resulting in conservative estimates of net benefits.

[10] This procedure was adopted due to the absence of replacement or repair cost estimates after the useful lives of the sample bridges.

**TABLE 1.—A Summary of (B-O)/K Ratios for Closed and Posted Sample Bridges in Wayne County, Ohio, 1979 (i = 12% and n = 15).**

| Bridge No. and Location | Scenario I Federal Aid | | Scenario II Force Account | | Scenario III Repair | |
|---|---|---|---|---|---|---|
| | Closed | Posted | Closed | Posted | Closed | Posted |
| 1. CHE 22-2.40 | 1.38 | 1.21 | 6.74 | 5.88 | 6.79 | 5.93 |
| 2. FRA 176-1.40 | 30.21 | 27.20 | * | * | * | * |
| 3. PAI 217-3.37 | 1.05 | 0.89 | 5.88 | 4.92 | 5.62 | 4.85 |
| 4. WOO 46-0.24 | 7.18 | 4.76 | 32.10 | 21.33 | — | — |
| 5. WOO 54-1.60 | 1.32 | 1.13 | 5.67 | 4.84 | 5.75 | 4.75 |
| 6. EAS 142-2.60 | —† | — | 24.77 | 17.62 | 31.61 | 22.34 |
| 7. MIL 48-2.60 | — | — | 70.44 | 59.29 | 67.09 | 51.01 |
| 8. MIL 108-5.09 | — | — | 17.99 | 14.17 | * | * |
| 9. SAL 2-3.02 | — | — | 53.97 | 43.77 | 43.28 | 34.87 |
| 10. SUG 105-2.06 | — | — | 54.48 | 48.22 | 43.66 | 38.42 |
| 11. CHE 154-2.73 | — | — | 5.01 | 4.51 | 4.53 | 3.85 |
| 12. CHI 95-1.24 | — | — | 5.78 | 4.54 | 32.23 | 25.39 |
| 13. CHI 133-2.10 | 1.33 | 0.93 | 4.79 | 3.36 | 5.34 | 3.74 |
| 14. CON 59-0.21 | 0.23 | 0.26 | 1.12 | 1.23 | — | — |
| 15. PLA 157-3.33 | — | — | 66.01 | 51.84 | 67.33 | 52.57 |

*Value exceeds the limit of the program.
†— Not included in scenario.

## ANALYSIS AND RESULTS

The analysis was carried out with a computer program (COMPRAN) developed in the Dept. of Agricultural Economics and Rural Sociology at The Ohio State University. A 12% discount rate was specified for the main analysis and 15% for the sensitivity analysis. Traffic growth was statistically estimated to be 1% per annum. A non-intercept linear regression model was used for the traffic forecasts after a +.9406 correlation between vehicle registration and population for Wayne County was established.[11]

Two separate computer runs were made for each scenario. The first run assumes that bridges are closed. This allows all vehicles to detour and hence total circuity cost to be used as a benefit estimate. The second run assumes that bridges are posted. Three sample bridges, namely PAI 217-3.37 (3), WOO 46-0.24 (4), and WOO 54-1.60 (5), are already limited to 1, 4, and 10 tons, respectively. Three limits were used for these bridges in this phase of the analysis. The non-posted bridges were assumed to be limited to 20-ton vehicles, restricting access to weight class 4 vehicles only.

Under the posted assumption, it is further assumed that 20% of the users will violate the posted limit. This assumption is based on a finding that about 22% of all loaded trucks exceed state weight limits (7).

A summary of (B-O)/K ratios is presented in Table 1. The table reveals that with the exception of one bridge in Scenario I, the ratios are all greater than 1. A ratio greater than 1 shows that net travel cost savings of motorists exceed repair or replacement costs of a given sample bridge. Ratios are given for both full closure and posting assumptions of sample bridges.

The frequent increase in (B-O)/K ratios from Scenario I to III generally indicates that repairing the bridges is a more cost-effective alternative than replacement on force account and federal aid program, in that order.

It is also evident from Table 1 that the rank of bridges for replacement or repairs varies between scenarios, but shows no variation between the closed and the posted assumptions. The only diference between the posted and the closed assumptions is in the magnitude of the (B-O)/K ratios; *i.e.,* they are lower for the posted assumptions. The explanation for this is that when the bridges were posted, the change in circuity costs was proportionately smaller than the reduction in the annual maintenance costs per bridge. The results of the sensitivity analysis in Appendix 7

[11]This prediction does not take into consideration the driving habits of motorists which could change after bridges are posted or closed.

**TABLE 2.—Summary of NPV for Posted and Closed Sample Bridges in Wayne County, Ohio, 1979 (i = 12% and n = 15).**

| | Scenario I | | | Scenario II | | | Scenario III | | |
|---|---|---|---|---|---|---|---|---|---|
| | Federal Aid | | | Force Account | | | Repair | | |
| | Closed | Posted | | Closed | Posted | | Closed | Posted | |
| Bridge No. and Location | NPV | NPV(a) | ΔNPV | NPV | NPV(a) | ΔNPV | NPV | NPV(a) | ΔNPV |
| 1. CHE 22-2.40 | 104,552 | 59,155 | 45,397 | 325,367 | 276,643 | 41,660 | 325,824 | 277,101 | 48,723 |
| 2. FRA 176-1.40 | 9,759,024 | 8,764,600 | 989,424 | 10,027,962 | 9,033,538 | 808,201 | 10,044,785 | 9,050,363 | 994,422 |
| 3. PAI 217-3.37 | 12,436 | —22,748 | 35,184 | 204,836 | 164,929 | 34,053 | 196,736 | 163,882 | 32,854 |
| 4. WOO 46-0.24 | 2,785,016 | 1,693,447 | 1,091,569 | 3,144,149 | 2,048,188 | 891,671 | — | — | — |
| 5. WOO 54-1.60 | 121,011 | 51,029 | 69,982 | 411,847 | 339,206 | 62,165 | 428,790 | 338,860 | 89,930 |
| 6. EAS 142-2.60 | —* | — | — | 548,834 | 383,903 | 134,391 | 557,692 | 388,771 | 218,921 |
| 7. MIL 48-2.60 | — | — | — | 946,720 | 734,126 | 182,849 | 946,608 | 730,738 | 215,870 |
| 8. MIL 108-5.09 | — | — | — | 819,800 | 635,376 | 149,797 | 863,811 | 677,398 | 186,413 |
| 9. SAL 2-3.02 | — | — | — | 667,088 | 538,651 | 104,889 | 668,199 | 535,439 | 132,760 |
| 10. SUG 105-2.06 | — | — | — | 673,550 | 594,653 | 64,690 | 674,326 | 591,441 | 82,885 |
| 11. CHE 154-2.73 | — | — | — | 141,455 | 121,724 | 17,528 | 144,032 | 116,323 | 27,709 |
| 12. CHI 95-1.24 | — | — | — | 403,784 | 299,149 | 85,283 | 469,830 | 366,861 | 102,969 |
| 13. CHI 133-2.10 | 187,212 | —35,954 | 223,166 | 589,863 | 366,696 | 186,586 | 605,658 | 382,491 | 223,167 |
| 14. CON 59-0.21 | —242,415 | —230,297 | 12,136 | 9,123 | 17,271 | 5,846 | — | — | — |
| 15. PLA 157-3.33 | — | — | — | 818,677 | 635,451 | 149,083 | 814,502 | 633,272 | 181,230 |

*— Not included in scenario.

follow the same pattern as Table 1. However, the (B-O)/K ratios are lower at a 15% discount rate than at 12%.

Table 2 presents a summary of the NPV for the three scenarios. For each sample bridge under the closed assumption, the NPV represents the potential net cost savings to motorists if the bridge should be rehabilitated under that scenario. The NPV's under the posted assumptions are presented under two columns. Under the first column headed NPV(a), the NPV's represent the potential net cost savings by motorists that were previously unaffected by the weight limit posting. The second column measures the change in NPV ($\Delta$NPV) and represents the potential net cost savings by motorists that were previously re-routed.

As with the (B-O)/K ratio, the NPV's for closed bridges except for one bridge in Scenario I are all positive, with the average for each scenario shown under the columns. The NPV's in Table 2 vary from bridge to bridge and generally increase from Scenario I to III for the same reason given for the trend in (B-O)/K ratios.

As pointed out, road and bridge rehabilitation costs are usually primarily covered by road user taxes. Motorists who use the road more frequently pay more in gasoline taxes. Secondly, the heavier vehicles pay more in axle-mile taxes because of their weights and higher fuel consumption. Alternatively, heavy vehicle motorists who frequently use the roads save more in re-routed costs when bridges or roads are rehabilitated. This suggests that the same motorists who benefit from the cost savings due to rehabilitation of the bridges generally bear the cost of replacement, repairs, and maintenance. It also suggests that users who derive more benefits from the roads or bridges generally pay more for their rehabilitation.

There are exceptions to this general statement. When motorists attach different priorities or weights to each trip, such as the movement of a perishable vs. durable farm commodity, the net benefits from each operation are not directly proportional to the user taxes paid under each condition. In addition, some states rely more on non-user revenues. There are also the secondary or spillover effects on residents within the area of influence of the road or bridge, such as the response of emergency vehicles which may bear no relationship to user charges.

The results of the sensitivity analysis in Appendix VIII follow the same pattern as Table 2. However, the NPV's are lower at a 15% discount rate. The low NPV's indicate that potential benefits of rehabilitation decrease if the funds could be invested in an alternative high yielding investment.

In Table 3, prioritization of bridges based on the results of this analysis is compared with the judgmental prioritization of bridges for force account replacement by the county engineers. Based on the county's current force account replacement budget of $214,000, six bridges could be replaced at an initial cost of $206,000. The net potential travel cost savings from replacing these bridges, after all future costs and benefits are discounted to present value at 12% discount rate, is $16,281,066. Based on the ranking system of the Wayne County Engineer's Office, however, three bridges could be replaced at an initial cost of $198,000 and a potential travel cost savings of $13,376,946. The difference in cost savings or efficiency gains is $2,904,119. If a fourth bridge on the county list is replaced, the budget is exceeded by $37,300. Thus, potential travel cost savings increase to $13,702,314 with efficiency gains of $2,578,752.

In Table 4, the (B-O)/K ratios for repairs and replacement (Scenarios II and III) are ranked to determine the optimum mix of scenarios that maximize travel cost savings from a fixed replacement and repair budget in Wayne County of $232,700. The results are compared with a similar mix of scenarios developed by the county engineers. This analysis reveals that five bridges could be replaced and four repaired at an initial total cost of $206,000. The sum of the NPV's of these nine bridges, after discounting all future costs and benefits at a 12% discount rate,

**TABLE 3.—A Comparison of NPV and Bridge Replacement Cost (Scenario II) for Bridges Based on County Priorities and the Results of This Analysis.**

| Bridge No. and Ranking Based on the Model | Replacement Cost (Scenario II) | NPV | Bridge No. and Ranking Based on County Priorities | Replacement Cost (Scenario II) | NPV |
|---|---|---|---|---|---|
| 2 | 62,000 | 10,027,962 | 3 | 40,000 | 204,836 |
| 7 | 12,000 | 949,720 | 4 | 96,000 | 3,144,149 |
| 15 | 12,000 | 818,677 | 2 | 62,000 | 10,027,962 |
| 10 | 12,000 | 673,550 | | 198,000 | 13,376,947 |
| 9 | 12,000 | 667,008 | 1 | 54,000 | 325,367 |
| 4 | 96,000 | 3,144,149 | | 252,000 | 13,702,314 |

is $18,138,224. Based on the county optimization of scenarios, two bridges could be replaced and four repaired at an initial cost of $217,000, with a potential travel cost savings of $15,070,181. The difference in NPV or efficiency gains between the two procedures is $1,526,662.

In Table 5, the NPV's of the five bridges assumed to have safety hazards and selected by the county engineers for repair or replacement are compared with the NPV's of the rest of the selected sample, using the results of Scenario II. The table indicates that the net potential cost savings from replacing the five critical bridges is about 71.5% of the total cost savings from replacing all of the 15 sample bridges. However, one bridge accounts for 50% and two bridges for 65% of the total cost savings.

**TABLE 4.—Comparison of Optimum Combination of Repair and Replacement Scenarios (II and III) Between Analysis and County Priorities.**

| Bridge No. | Analysis Results: B-O/K | Analysis Results: Replacement or Repair Cost | NPV | Replacement or Repair Option |
|---|---|---|---|---|
| 2 | * | 62,000 | 10,027,962 | Replacement |
| 8 | * | 1,000 | 863,811 | Repair |
| 7 | 70.44 | 12,000 | 946,720 | Replacement |
| 15 | 67.33 | 3,000 | 814,502 | Repair |
| 10 | 54.48 | 12,000 | 673,550 | Replacement |
| 9 | 53.97 | 12,000 | 667,008 | Replacement |
| 12 | 32.23 | 5,000 | 469,830 | Repair |
| 4 | 32.10 | 96,000 | 3,144,149 | Replacement |
| 6 | 31.61 | 3,000 | 557,692 | Repair |
| | | 206,000 | 18,138,224 | |
| | County Priorities | | | |
| 4 | 32.10 | 96,000 | 3,144,149 | Replacement |
| 3 | 5.62 | 12,000 | 196,736 | Repair |
| 2 | * | 62,000 | 10,027,962 | Replacement |
| 1 | 6.79 | 15,000 | 325,824 | Repair |
| 5 | 5.75 | 20,000 | 428,790 | Repair |
| 7 | 54.48 | 12,000 | 946,720 | Repair |
| | | 217,000 | 15,070,181 | |

*Value exceeds the limit of the program.

**TABLE 5.—A Comparison of the Safety Hazard Bridges with the Rest of Sample (Scenario II).**

| Safety Hazard Bridges: Bridge No. and Location | NPV | Rest of Sample: Bridge No. and Location | NPV |
|---|---|---|---|
| 1. CHE 22-2.40 | 325,367 | 6. EAS 142-2.60 | 548,834 |
| 2. FRA 176-1.40 | 10,027,962 | 7. MIL 48-2.60 | 946,720 |
| 3. PAI 217-3.37 | 204,836 | 8. MIL 108-5.09 | 819,800 |
| 4. WOO 46-0.24 | 3,144,149 | 9. SAL 2-3.02 | 667,088 |
| 5. WOO 54-1.60 | 411,847 | 10. SUG 105-2.06 | 673,550 |
| | 14,114,161 | 11. CHE 154-2.73 | 141,455 |
| | | 12. CHI 95-1.24 | 403,784 |
| | | 13. CHI 133-2.10 | 589,863 |
| | | 14. CON 59-0.21 | 9,123 |
| | | 15. PLA 157-3.33 | 818,677 |
| | | | 5,618,894 |

## CONCLUSIONS AND IMPLICATIONS

The NPV and (B-O)/K ratios vary from bridge to bridge and decrease with an increase in discount rate. These values are determined by capital outlays, maintenance costs, circuity distances, and traffic counts. When the bridges were posted, the results were further influenced by the level of posting and the number of trucks that had to detour or violate the posted limit.

The magnitude of the NPV's implies that there is a substantial potential savings by motorists when all but one bridge is rehabilitated. The difference in NPV's between the posted and the closed assumptions also implies that substantial costs are incurred by motorists when bridges are posted. Similarly, (B-O)/K ratios > 1 suggest a justification for investment in these bridges and also serve as a basis for ranking the bridges for repair or replacement.

The potential increase in savings from use of this circuity cost model compared to the county procedure has important implications for local decision making on rehabilitation or closure of rural bridges. However, these results must be carefully interpreted. First, the bridges in the sample may not be fully representative of all bridges in Wayne County. Second, county engineers may take into consideration factors other than those included in this model in posting or rehabilitating bridges. Vocal and/or influential members of the community may get a higher priority placed on a bridge critical to their needs. There may also be circumstances involving emergency vehicle response time that result in a higher priority placed on bridges critical to this objective. On the other hand, data on actual circuity cost differences are not available to most county engineers even if they wanted to utilize this information.

For interscenario comparisons of results, there is generally an increase in NPV and (B-O)/K ratios in going from federal aid (Scenario I) to major repair (Scenario III). This does not imply that repairs are preferable to replacement. It could reflect the fact that some scenarios (*e.g.*, Scenario I) may not be cost-effective. In addition, secondary benefits such as safety, comfort, etc., which may vary among scenarios, are not included.

More research is needed to explore the relationship between road deterioration and vehicle weight. In addition, further study is needed to assess the impact of bridge width and height on the movement of certain types of farm, construction, mining, and oil equipment. Such findings will be useful in revising the axle-mile tax and establishing a penalty fine structure that will deter weight violators. This fine structure should also take into consideration the circuity costs that violators hope to avoid, the frequency of use of the road by violators, and the probability that a violator will be caught.

Another area that merits further study is a broadening of the circuity cost model to incorporate secondary benefits and costs such as inventory cost, changes in property values, and the productive potential of the adjoining roadbeds that are abandoned after the bridges are closed. Such variables will help to make interscenario comparisons possible and improve the generality and acceptance of the model.

It is further suggested that the model be replicated in another rural county. This second study might focus on county situations different from Wayne County for comparison purposes and generalization of the model. This raises the issue of the costs and benefits of utilizing this model for improved decisionmaking. Limited evidence from the Wayne County application suggests potentially high net benefits from the use of the model. For example, the cost of doing this analysis, including graduate student salary, travel, computer, and county engineer staff time, is estimated at around $15,000. If the earlier cost of travel counts by the CETA workers are included, the total might be $50,000. Even the most conservative estimate of potential net savings from use of the model exceeds $1.5 million.

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# APPENDIX

**APPENDIX I.—Results of Comparison of Bridge Groups Using the t and the f Tests.**

| | Condition | Age |
|---|---|---|
| **Variance Test (f)** | | |
| **Bridge Groups** | **Condition** | **Age** |
| 1 and 3 | 4.72* | 1.36** |
| 2 and 3 | 7.12* | 2.47** |
| **Mean Test (t)** | | |
| **Bridge Groups** | **Condition** | **Age** |
| 1 and 2 | 3.18* | 2.03* |
| 2 and 3 | 1.69** | 1.912* |

*Significant at the 1% level.
**Significant at the 5% level.

**APPENDIX II.—Circuity Distances and Traffic Counts by Weight Class.**

| Bridge No. and Location | Circuity Distance (miles) | Total Annual Traffic Count | Traffic Count for Weight Class I | Traffic Count for Weight Class II | Traffic Count for Weight Class III | Traffic Count for Weight Class IV |
|---|---|---|---|---|---|---|
| 1. CHE 22-2.40 | 2.5 | 28,150 | 19,395 | 4,757 | 1,464 | 2,534 |
| 2. FRA 176-1.40 | 3.1 | 560,275 | 358,575 | 112,055 | 56,028 | 33,616 |
| 3. PAI 217-3.37 | 1.4 | 33,215 | 21,923 | 7,240 | 1,462 | 2,590 |
| 4. WOO 46-0.24 | 1.2 | 469,400 | 336,090 | 54,450 | 34,266 | 44,593 |
| 5. WOO 54-1.60 | 1.8 | 53,655 | 38,417 | 9,282 | 2,683 | 3,273 |
| 6. EAS 142-2.60 | 1.6 | 65,333 | 38,938 | 21,690 | 2,157 | 2,548 |
| 7. MIL 48-2.60 | 2.0 | 90,885 | 64,347 | 22,176 | 1,817 | 2,545 |
| 8. MIL 108-5.09 | 1.8 | 90,155 | 63,830 | 21,277 | 1,442 | 3,606 |
| 9. SAL 2-3.02 | 1.9 | 63,510 | 42,933 | 14,353 | 4,128 | 3,176 |
| 10. SUG 105-2.06 | 1.6 | 78,840 | 59,130 | 10,643 | 5,125 | 3,942 |
| 11. CHE 154-2.73 | 1.6 | 20,805 | 14,335 | 3,558 | 728 | 2,185 |
| 12. CHI 95-1.24 | 1.1 | 82,125 | 55,845 | 20,039 | 2,959 | 3,285 |
| 13. CHI 133-2.10 | 1.8 | 70,080 | 47,654 | 16,960 | 2,943 | 2,523 |
| 14. CON 59-0.21 | 1.0 | 18,250 | 13,176 | 1,059 | 1,460 | 2,555 |
| 15. PLA 157-3.33 | 2.0 | 76,650 | 51,968 | 19,163 | 2,223 | 3,296 |

**APPENDIX III.—Average Vehicle Operating Cost ($/mile) by Weight Class, Ohio, 1979.**

| Weight Class | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| **Total Miles per Year** | 15,000 | 15,000 | 30,000 | 100,000 |
| **Variable Cost** | | | | |
| Maintenance | 0.026 | 0.04 | 0.05 | 0.13 |
| Tires, Tubes, and Equipment | 0.021 | 0.03 | 0.03 | 0.04 |
| Fuel and Lubricants | 0.053 | 0.08 | 0.13 | 0.17 |
| Subtotal | 0.100 | 0.15 | 0.21 | 0.34 |
| **Fixed Cost** | | | | |
| Depreciation | 0.10 | 0.15 | 0.17 | 0.12 |
| Interest, License, Taxes, and Insurance | 0.08 | 0.11 | 0.12 | 0.12 |
| Administrative and Garaging | — | — | 0.05 | 0.13 |
| Subtotal | 0.18 | 0.26 | 0.34 | 0.37 |
| Fixed and Variable Costs | 0.28 | 0.41 | 0.56 | 0.71 |
| Labor Cost | 0.18 | 0.19 | 0.31 | 0.46 |
| Total | 0.46 | 0.60 | 0.87 | 1.17 |

Sources: (44, 45).

## APPENDIX IV.—Calculation of Circuity Cost.

In this appendix, the data for bridge number 1 (CHE 22-2.40) is used to illustrate how circuity costs for each sample bridge are calculated for the closed and posted assumptions. The data required for the calculation are: circuity distance, vehicle operating costs per mile by weight class, and annual traffic count by weight class.

Circuity distance (CD) for CHE 22-2.40 is 2.5 miles. Vehicle operating costs and traffic counts by weight classes are as follows:

| Weight Classes | Vehicle Operating Cost (VOC)/Mile | Annual Traffic Count (Nu) |
|---|---|---|
| 1 | 0.464 | 19,395 |
| 2 | 0.601 | 4,757 |
| 3 | 0.872 | 1,464 |
| 4 | 1.17 | 2,534 |

Circuity cost for each weight class is given by the formula (VOC x CD x Nu). Based on this, the circuity cost for all four weight classes is calculated as follows:

| Weight Class | VOC | | CD | | Nu | | Circuity Cost |
|---|---|---|---|---|---|---|---|
| 1 | 0.464 | x | 2.5 | x | 19,395 | = | $22,498.20 |
| 2 | 0.601 | x | 2.5 | x | 4757 | = | 7,147.40 |
| 3 | 0.872 | x | 2.5 | x | 1464 | = | 3,191.50 |
| 4 | 1.17 | x | 2.5 | x | 2574 | = | 7,411.95 |
| Total Circuity Cost | | | | | | = | $40,249.05 |

The total circuity cost of $40,249.05 is the sum of the circuity costs for all weight classes.

When bridge 1 is posted, all vehicles within the fourth weight class are compelled to detour. However, it is assumed that 20% of all vehicles within the fourth weight class violate the posted limit. The circuity cost for vehicles that reroute is given by (1 — .20) x (7411.95) or 5929.56. The circuity cost for motorists who still use the bridge is (40,249.05 — 5929.56) or 34,319.49.

## APPENDIX V.—Total Circuity Costs for the Posted and Closed Assumptions.

| Bridge No. and Location | Circuity Cost for Closed Assumption | Circuity Cost for Posted Assumption |
|---|---|---|
| 1. CHE 22-2.40 | 40,249.05 | 34,319.49 |
| 2. FRA 176-1.40 | 999,918.31 | 900,378.12 |
| 3. PAI 217-3.37 | 26,360.14 | 21,538 06 |
| 4. WOO 46-0.24 | 324,868.71 | 214,681 65 |
| 5. WOO 54-1.60 | 53,231.29 | 44,347.95 |
| 6. EAS 142-2.60 | 57,543.97 | 40,858.29 |
| 7. MIL 48-2.60 | 95,493.02 | 74,169.54 |
| 8. MIL 108-5.09 | 86,138.95 | 67,771.89 |
| 9. SAL 2-3.02 | 68,138.95 | 55,027.19 |
| 10. SUG 105-2.06 | 68,662.23 | 60,474.79 |
| 11. CHE 154-2.73 | 19,169.69 | 16,432 59 |
| 12. CHI 95-1.24 | 48,814.26 | 38,216.03 |
| 13. CHI 133-2.10 | 80,261.36 | 55,261.36 |
| 14. CON 59-0.21 | 11,012.58 | 10,503.42 |
| 15. PLA 157-3.33 | 82,849.76 | 64,422.62 |

**APPENDIX VI.—Initial Capital Outlays and Annual Maintenance Costs of Bridges for Posted and Closed Assumptions.**

| Bridge Number and Location | Scenario I | | | Scenario II | | | Scenario III | | | Life Span | Number of Repairs After Year 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | K* | Oc† | Op‡ | K | Oc | Op | K | Oc | Op | | |
| 1. CHE 22-2.40 | 270,000 | 990 | 550 | 54,000 | 765 | 425 | 15,000 | 765 | 425 | 15 | 0 |
| 2. FRA 176-1.40 | 334,000 | 900 | 500 | 62,000 | 900 | 500 | 5,000 | 900 | 500 | 20 | 0 |
| 3. PAI 217-3.37 | 225,000 | 885 | 475 | 40,000 | 603 | 375 | 12,000 | 830 | 350 | 15 | 0 |
| 4. WOO 46-0.24 | 450,000 | 1,620 | 900 | 96,000 | 1,323 | 735 | — | — | — | — | — |
| 5. WOO 54-1.60 | 373,000 | 1,350 | 750 | 84,000 | 1,170 | 650 | 20,000 | 1,060 | 600 | 10 | 0 |
| 6. EAS 142-2.60 | — | — | — | 22,000 | 320 | 200 | 3,000 | 360 | 200 | 15 | 1 |
| 7. MIL 48-2.60 | — | — | — | 12,000 | 225 | 125 | 5,000 | 315 | 175 | 20 | 1 |
| 8. MIL 108-5.09 | — | — | — | 48,000 | 135 | 75 | 1,000 | 225 | 125 | 15 | 1 |
| 9. SAL 2-3.02 | — | — | — | 12,000 | 305 | 175 | 5,000 | 315 | 175 | 15 | 1 |
| 10. SUG 105-2.06 | — | — | — | 12,000 | 270 | 150 | 5,000 | 270 | 150 | 15 | 1 |
| 11. CHE 154-2.73 | — | — | — | 33,000 | 540 | 300 | 12,000 | 504 | 280 | 15 | 1 |
| 12. CHI 95-1.24 | — | — | — | 8,400 | 180 | 100 | 5,000 | 270 | 150 | 10 | 1 |
| 13. CHI 133-2.10 | 558,000 | 2,025 | 1,125 | 148,000 | 2,025 | 1,125 | 30,000 | 2,025 | 1,125 | 15 | 1 |
| 14. CON 59-0.21 | 315,000 | 1,170 | 650 | 69,000 | 900 | 500 | — | — | — | — | — |
| 15. PLA 157-3.33 | — | — | — | 12,000 | 225 | 125 | 3,000 | 360 | 200 | 15 | 1 |

*K = Capital outlay.
†Oc = Annual maintenance cost for closed assumption.
‡Op = Annual maintenance cost for posted assumption.

**APPENDIX VII.—A Summary of (B-O)/K Ratios for Closed and Posted Sample Bridges in Wayne County, Ohio, 1979 (i = 15% and n = 15).**

| Bridge No. and Location | Scenario I Federal Aid | | Scenario II Force Account | | Scenario III Repair | |
|---|---|---|---|---|---|---|
| | Closed | Posted | Closed | Posted | Closed | Posted |
| 1. CHE 22-2.40 | 1.14 | 1.00 | 5.73 | 4.97 | 7.30 | 6.38 |
| 2. FRA 176-1.40 | 24.49 | 22.07 | * | * | * | * |
| 3. PAI 217-3.37 | 0.88 | 0.74 | 5.02 | 4.18 | 6.12 | 5.21 |
| 4. WOO 46-0.24 | 5.84 | 3.87 | 27.06 | 17.91 | — | — |
| 5. WOO 54-1.60 | 1.09 | 0.93 | 4.83 | 4.11 | 5.74 | 4.75 |
| 6 EAS 142-2.60 | —† | — | 20.06 | 14.82 | 45.02 | 31.85 |
| 7. MIL 48-2.60 | — | — | 63.96 | 49.73 | 85.83 | 66.72 |
| 8. MIL 108-5.09 | — | — | 14.64 | 11.53 | * | * |
| 9. SAL 2-3.02 | — | — | 45.36 | 36.75 | 51.75 | 41.73 |
| 10. SUG 105-2.06 | — | — | 45.78 | 40.46 | 52.20 | 45.94 |
| 11. CHE 154-2.73 | — | — | 4.36 | 3.83 | 5.60 | 4.77 |
| 12. CHI 95-1.24 | — | — | 4.71 | 3.70 | 33.83 | 26.61 |
| 13. CHI 133-2.10 | 1.10 | 0.77 | 4.10 | 2.86 | 7.28 | 5.08 |
| 14. CON 59-0.21 | 0.21 | 0.27 | 1.03 | 1.08 | — | — |
| 15. PLA 157-3.33 | — | — | 50.40 | 43.16 | 87.26 | 68.06 |

*Value exceeds the limit of the program.

†— Not included in scenario.

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